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(54) **SURFACE FOR FILTERING A PLURALITY OF FREQUENCY BANDS**

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H01Q 15/00 (2006.01)

(52) **U.S. Cl.**
CPC ***H01Q 15/0013*** (2013.01)

(58) **Field of Classification Search**
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USPC 342/4
See application file for complete search history.

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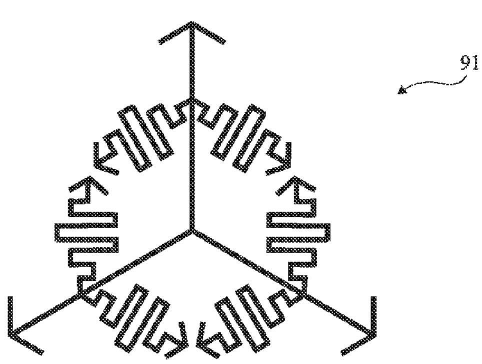
(57) **ABSTRACT**

The invention relates to a surface suitable for filtering a plurality of frequency bands, said surface including a set of separate identical basic conductive units (**31**) that are reproduced in a periodic arrangement on a dielectric substrate (**10**). The basic unit includes: a tripole consisting of three identical segments (**12**) that extend radially from a center (**14**); and two arms (**32**) that extend symmetrically from an intermediate point of each segment, said intermediate point being located at a common distance (D_b) from the center (**14**) for each of the segments (**12**). The general directions of both arms form an angle of approximately 120° and define an arrowhead pointed toward the outside, wherein the arms (**32**) corresponding to two separate segments (**12**) do not intersect.

11 Claims, 3 Drawing Sheets



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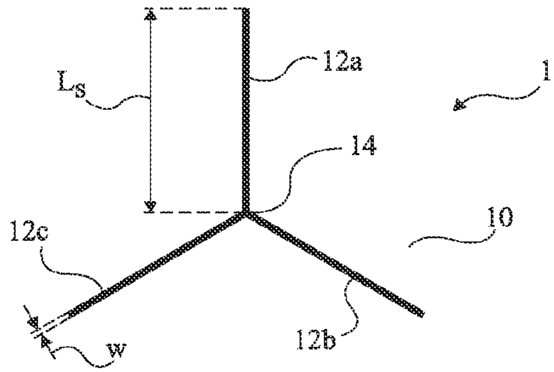

Fig 1

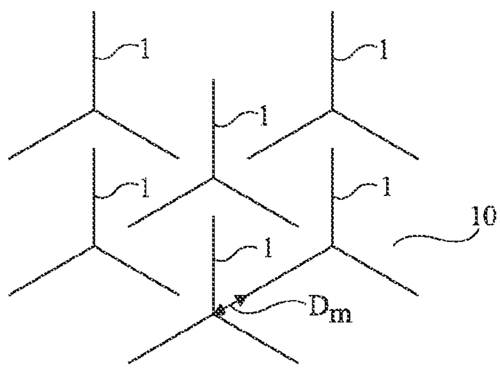

Fig 2

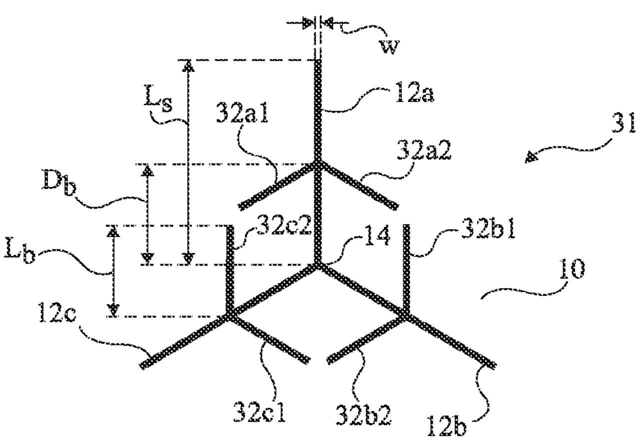

Fig 3

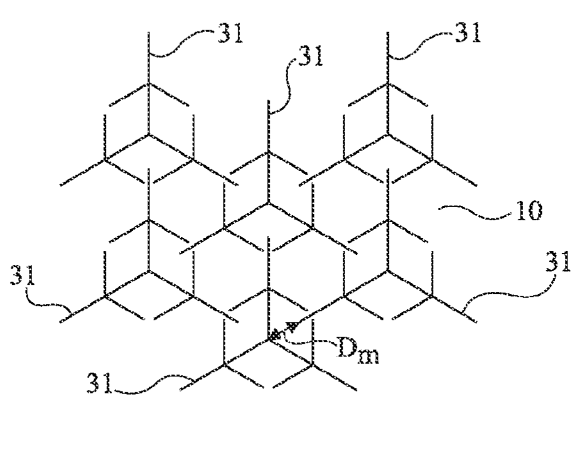

Fig 4

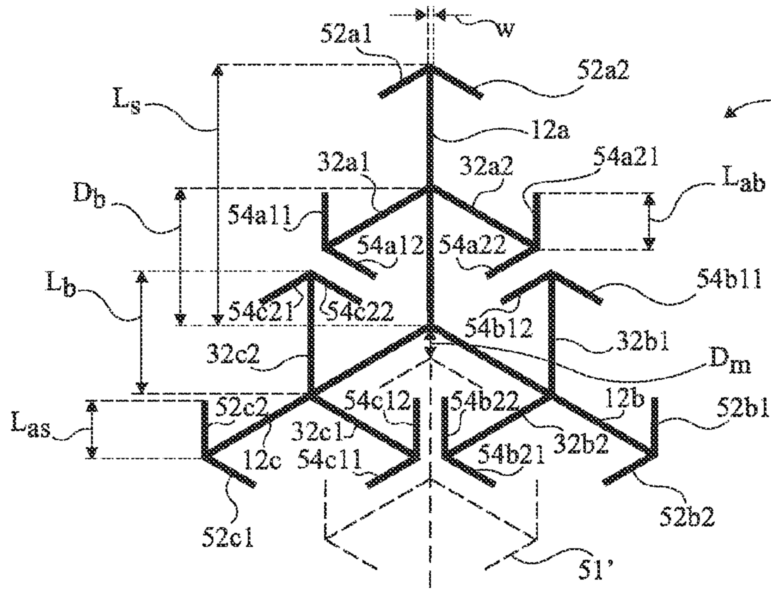

Fig 5

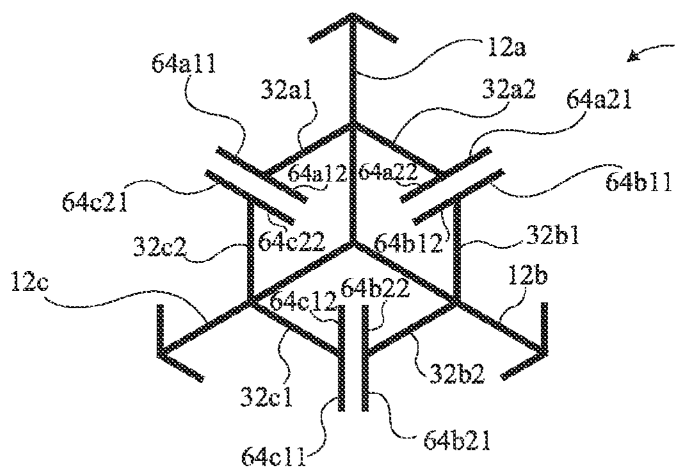

Fig 6

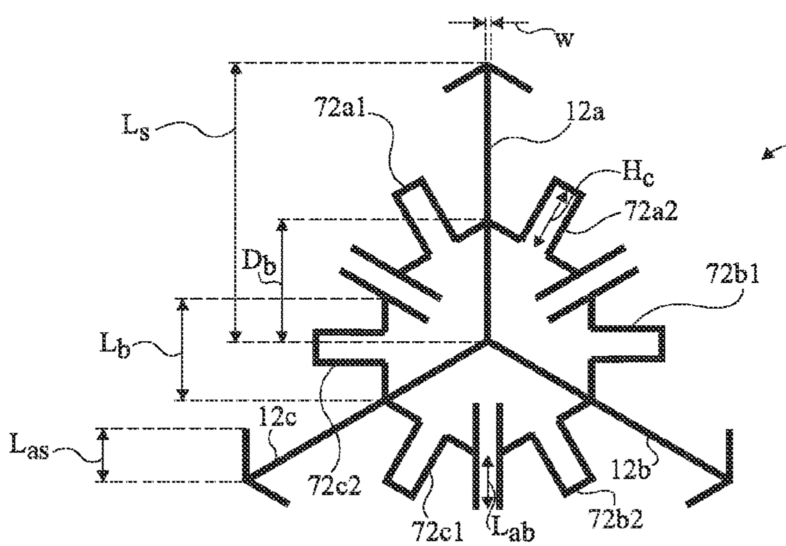

Fig 7

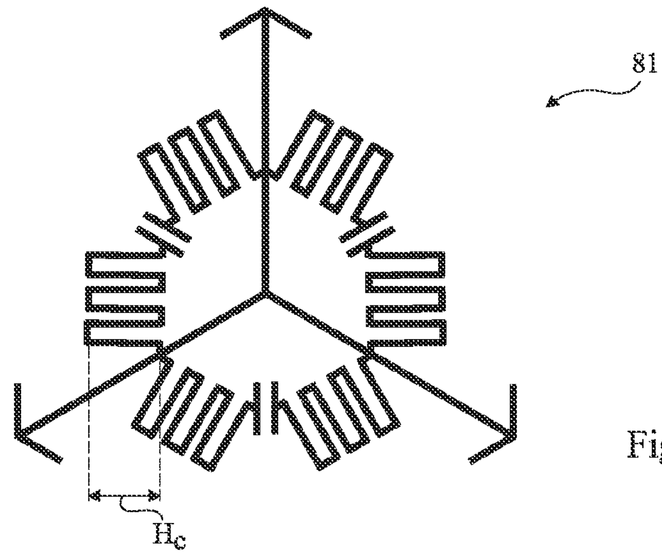

Fig 8

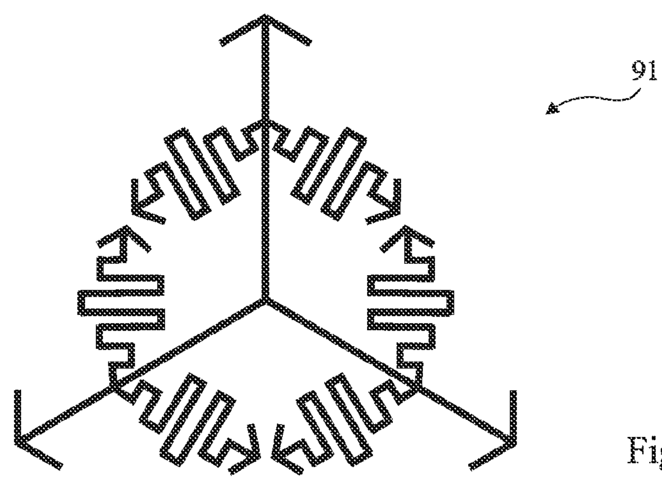

Fig 9

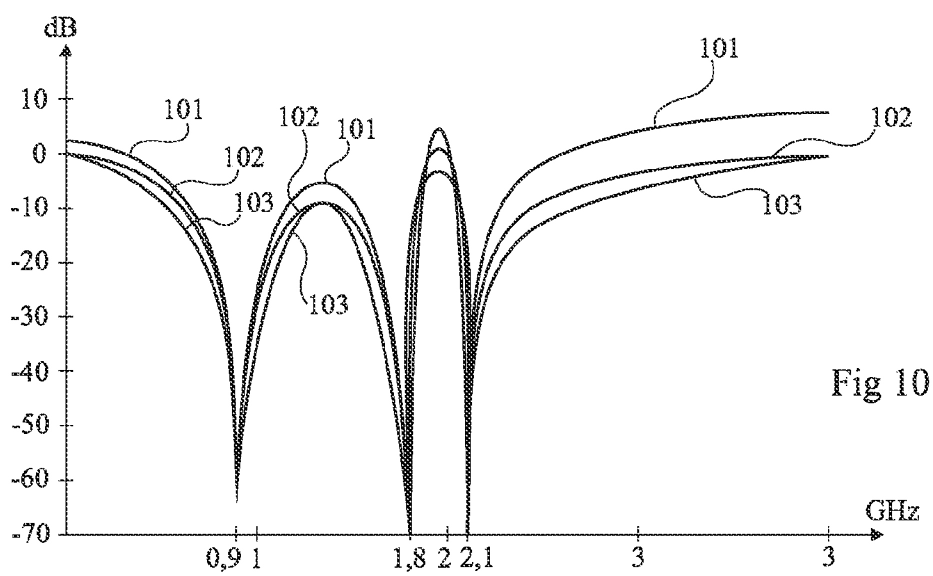

Fig 10

SURFACE FOR FILTERING A PLURALITY OF FREQUENCY BANDS

FIELD OF THE INVENTION

The present disclosure relates to a frequency-selective surface, that is, a surface capable of shielding electromagnetic waves belonging to certain frequency bands.

DISCUSSION OF PRIOR ART

Frequency-selective surfaces are generally called FSS in the art. They comprise a set of identical elementary conductive patterns, repeated according to a periodic layout on a surface of a dielectric support. The shape and the dimensions of the elementary pattern, the arrangement of the periodic layout, and the characteristics of the conductive material of the pattern and of the dielectric material of the support are the main factors determining the filtering properties of the surface.

One of the targeted applications relates to the selective shielding of a building or of a room of a building against certain electromagnetic waves. The frequencies which are generally desired to be filtered especially comprise the carrier frequencies of GSM-type mobile telephony systems (0.9, 1.8, and 2.1 GHz), as well as the carrier frequencies of Wi-Fi-type wireless computer network systems (2.4 and 5.4 GHz).

The dielectric support may be a substrate based on epoxy or on plastic on which the conductive patterns are formed by deposition of conductive layers, according to manufacturing methods similar to printed circuit manufacturing methods. It has also been provided to form frequency-selective surfaces directly on paper- or cardboard-type supports, for example, by printing with a conductive ink. This last embodiment especially has the advantage of significantly decreasing the cost of such surfaces.

FIG. **1** is a top view schematically showing an elementary conductive pattern **1** of a frequency-selective surface. Pattern **1**, formed on a surface of a dielectric support **10**, is a tripole formed of three identical segments **12***a*, **12***b*, and **12***c* of length L_s, extending in a star from a center **14**. Segments **12***a* to **12***c* form, two-by-two, angles of approximately 120°.

FIG. **2** is a top view schematically showing a portion of a frequency-selective surface formed by the repeating, according to a periodic layout on dielectric support **10**, of elementary pattern **1** of FIG. **1**. Pattern **1** is repeated by translation along each of the directions of segments **12***a* to **12***c* of the tripole, so that a same non-zero distance D_m separates each outer end of a segment of a pattern from the center of a neighboring pattern. The translation is repeated until it covers the entire targeted surface.

The surface thus formed has a resonance frequency essentially depending on the parameters relative to length L_s of the tripole segments and to distance D_m between neighboring patterns. Such a surface has the property of filtering the electromagnetic waves belonging to a frequency band centered on its resonance frequency. The filtering efficiency also depends on width W and on the thickness (not shown in the drawing) of the pattern, as well as on the thickness (not shown in the drawing) of dielectric support **10**.

A disadvantage of the frequency-selective surface described in relation with FIGS. **1** and **2** is that its frequency response depends on the angle of incidence of the electromagnetic waves with respect to the surface, as well as on the polarization of the incident electromagnetic waves.

Further, this surface only enables to filter a single frequency band centered on its resonance frequency. Thus, to filter different bands, for example GSM frequencies (on the order of 0.9, 1.8, and 2.1 GHz) and/or Wi-Fi frequencies (on the order of 2.4 and 5.4 GHz), frequency-selective surfaces adapted to each of the targeted bands should be stacked.

SUMMARY

Thus, an object of an embodiment of the present invention is to provide a frequency-selective surface overcoming at least some of the disadvantages of existing solutions.

An object of an embodiment of the present invention is to provide such a surface having filtering properties independent from the angle of incidence and from the polarization of incident electromagnetic waves.

An object of an embodiment of the present invention is to provide such a surface which is capable of filtering several different frequency bands.

An object of an embodiment of the present invention is to provide such a surface having a relatively low conductive pattern coverage rate.

Thus, an embodiment of the present invention provides a surface capable of filtering a plurality of frequency bands, this surface comprising a set of separate identical elementary conductive patterns, repeated according to a periodic layout on a dielectric support, the elementary pattern comprising: a tripole formed of three identical segments extending in a star from a center; and two branches extending symmetrically from an intermediate point of each segment, this intermediate point being located at a same distance from the center for each of the segments, the general directions of the two branches forming an angle of approximately 120° and defining an outward-pointing arrowhead, the branches associated with two different segments being non-secant.

According to an embodiment of the present invention, the segments of the tripole form, two-by-two, angles of approximately 120°.

According to an embodiment of the present invention, the elementary pattern further comprises two first identical fins extending symmetrically from the end of each segment, the first fins forming an angle of approximately 120° and defining an arrowhead directed towards the outside of the pattern.

According to an embodiment of the present invention, the elementary pattern further comprises two first identical fins extending from the free end of each branch, each second fin forming an angle of approximately 60° with the general direction of the branch.

According to an embodiment of the present invention, the second fins of each branch form together an angle of approximately 120° and defining an arrowhead directed towards the outside of the pattern.

According to an embodiment of the present invention, the second fins of each branch are aligned along a same direction, this direction intersecting the direction of the segment from which the branch originates.

According to an embodiment of the present invention, the branches comprise at least one crenel-shaped extension along a direction intersecting the general direction of the branch.

According to an embodiment of the present invention, the elementary pattern is repeated by translation along each of the directions of the segments of the tripole so that a same distance separates each end of a segment of a pattern from the center of a neighboring pattern.

According to an embodiment of the present invention, the surface is capable of filtering three frequency bands respectively centered on 0.9, 1.8, and 2.1 GHz.

According to an embodiment of the present invention, the surface is capable of filtering two frequency bands respectively centered on 2.4 and 5.4 GHz.

According to an embodiment of the present invention, the dielectric support is a paper- or cardboard-type support and the conductive patterns are formed by printing with a conductive ink.

Another embodiment of the present invention provides a use of the above-mentioned surface to filter three frequency bands located within the range from 0.9 to 5.4 GHz, wherein the overall dimensions of an elementary pattern approximately range from 1 to 10 centimeters, the lengths of each of these segments, branches, and fins being adjusted to select the three targeted frequency bands.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features and advantages of the present invention will be discussed in detail in the following non-limiting description of specific embodiments in connection with the accompanying drawings, among which:

FIG. **1**, previously-described, is a top view schematically showing an elementary conductive pattern of a frequency-selective surface;

FIG. **2**, previously-described, is a top view schematically showing a portion of a frequency-selective surface formed by repeating of the elementary pattern of FIG. **1**;

FIG. **3** is a top view schematically showing an embodiment of an elementary conductive pattern of a frequency-selective surface;

FIG. **4** is a top view schematically showing a portion of a frequency-selective surface formed by repeating of the elementary pattern of FIG. **3**;

FIGS. **5** to **9** are simplified top views showing different alternative embodiments of the elementary conductive pattern of FIG. **3**; and

FIG. **10** is a diagram showing the frequency responses of a surface formed from the elementary pattern of FIG. **5**, for elementary waves having different angles of incidence.

DETAILED DESCRIPTION

For clarity, the same elements have been designated with the same reference numerals in the different drawings and, further, the various drawings are not to scale.

FIG. **3** is a top view schematically showing an embodiment of an elementary conductive pattern **31** of a frequency-selective surface.

As an example, the conductive material may be aluminum, gold, copper, silver, carbon, iron, platinum, graphite, or a conductive alloy of several of these materials. Generally, the higher the electric conductivity of the material, the better the filtering performed by the surface.

Pattern **31**, formed on a surface of a dielectric support **10**, comprises a basic tripole formed of three approximately identical segments **12***a*, **12***b*, and **12***c* of length L_s, extending in a star from a center **14**. Segments **12***a* to **12***c* form, two-by-two, angles of approximately 120°, for example, ranging between 110 and 130°.

Pattern **31** further comprises, for each segment **12***a*, **12***b*, **12***c*, two substantially identical branches, respectively **32***a***1** and **32***a***2**, **32***b***1** and **32***b***2**, and **32***c***1** and **32***c***2**, extending from an intermediate point of the segment, substantially symmetrically with respect to the segment direction. In this example, branches **32** have the shape of bars with a length L_b. On each segment **12**, the intermediate point is located approximately at a same distance D_b from center **14**. The general directions of the two branches **32** form an angle of approximately 120°, for example, ranging between 110 and 130°, and defining an arrowhead directed towards the outside of the pattern. Further, branches **32** associated with two different segments **12** are non secant.

FIG. **4** is a top view schematically showing a portion of an embodiment of a frequency-selective surface formed by the repeating, according to a periodic layout on dielectric support **10**, of elementary pattern **31** of FIG. **3**. Pattern **31** is repeated by translation along each of the directions of segments **12***a* to **12***c* of the basic tripole, so that a same non-zero distance D_m separates each outer end of a segment of a pattern **31** from center **14** of a neighboring pattern **31**. The translation operation is repeated until the entire targeted surface is covered. It should be noted that the dimensions of the elementary pattern and distance D_m are selected to be such that the elementary patterns are separate.

The frequency response of the surface thus formed essentially depends on length L_s of segments **12**, on length L_b of branches **32**, on distance D_b between the intermediate starting point of branches **32** of a segment **12** and center **14** of the pattern, and on distance D_m between neighboring patterns.

The inventors have observed that such a surface has three main resonance frequencies. The first resonance frequency essentially depends on length L_s of segments **12** and on distance D_m between neighboring patterns. The second resonance frequency essentially depends on length L_b of branches **32** and on distance D_b between center **14** of the pattern and the intermediate point of segment **12** from which the branches originate. The third resonance frequency depends on all the above-mentioned parameters.

Such a surface has the property of filtering the electromagnetic waves belonging to three different frequency bands centered on its three main resonance frequencies. In practice, a simulation software is used to test different combinations of parameters by performing progressive adjustments to obtain a set of parameters adapted to the targeted frequency bands.

In the embodiment of FIG. **4**, the setting of the first and second resonance frequencies is relatively easy, but it is difficult to adjust the third resonance frequency without modifying the first two frequencies.

Further, the three resonance frequencies of the surface of FIG. **4** remain slightly dependent on the angle of incidence and on the polarization of electromagnetic waves.

FIG. **5** is a top view schematically showing another embodiment of an elementary conductive pattern **51** of a frequency-selective surface. Pattern **51** shows all the elements of pattern **31** of FIG. **3**. It further comprises two substantially identical fins of length L_{as}, respectively **52***a***1** and **52***a***2**, **52***b***1** and **52***b***2**, and **52***c***1** and **52***c***2**, extending from the outer end of each segment **12**, substantially symmetrically with respect to the segment direction. Fins **52** of each segment **12** form together an angle of approximately 120°, for example, ranging between 110 and 130°, and define an arrowhead directed towards the outside of the pattern.

In an embodiment, pattern **51** further comprises two substantially identical fins of length L_{ab}, respectively **54***a***11** and **54***a***12**, **54***a***21** and **54***a***22**, **54***b***11** and **54***b***12**, **54***b***21** and **54***b***22**, **54***c***11** and **54***c***12**, and **54***c***21** and **54***c***22**, extending from the outer end of each branch **32** (on the side of the branch opposite to the segment from which it originates), substantially symmetrically with respect to the general branch direction. Fins **54** of each branch **32** form together an angle of approximately 120°, for example, ranging between 110 and 130°, and define an outward-pointing arrowhead. The pattern dimensions are selected so that fins associated with different segments or branches are not secant and do not intersect the other segments and branches of the pattern.

FIG. **5** shows, in dotted lines, a portion of a pattern **51'** corresponding to a translation of pattern **51** along the direction of segment **12***a* of pattern **51**. In this example, fins **52** of the segment of pattern **51'** closest to center **14** of pattern **51** are located in the space delimited by segments **12***b* and **12***c* and by branches **32***b***2** and **32***c***1** of pattern **51**. A non-zero distance D_m separates center **14** of pattern **51** from the end of the closest segment **12**. It should be understood that other patterns (not shown) of a frequency-selective surface are formed similarly, by translation along the directions of the other segments **12**, according to a periodic layout of the type described in relation with FIG. **4**.

The surface thus formed has three main distinct resonance frequencies. These three resonance frequencies are independent from the angle of incidence and from the polarization of electromagnetic waves. Further, the introduction of additional parameters L_{as} and L_{ab} relative to the length of fins **52** and **54** increases resonance frequency setting possibilities.

The strong interleaving of the elementary patterns is considered to contribute to ensuring a behavior of the surface independent from the angle of incidence and from the polarization of electromagnetic waves. Thus, it will be ascertained to maintain parameter D_m relative to the distance between neighboring patterns relatively low.

FIG. **6** is a top view schematically showing an alternative embodiment of the elementary conductive pattern of FIG. **5**. Pattern **61** of FIG. **6** differs from the pattern of FIG. **5** by the orientation of the fins associated with branches **32**. In pattern **61**, two identical fins **64** (respectively **64***a***11** and **64***a***12**, **64***a***21** and **64***a***22**, **64***b***11** and **64***b***12**, **64***b***21** and **64***b***22**, **64***c***11** and **64***c***12**, and **64***c***21** and **64***c***22**) associated with a branch **32** each form an angle of approximately 60°, for example, ranging between 55 and 65°, with the general branch direction, and are substantially aligned along a same direction, this direction intersecting the direction of segment **12** from which branch **32** originates.

Like pattern **51** of FIG. **5**, pattern **61** provides surfaces with three resonance frequencies. It especially enables to obtain resonance frequencies different from those obtained from pattern **51**, and has the same setting possibilities and the same insensitivity to the orientation and to the polarization of electromagnetic waves as pattern **51**.

FIG. **7** is a top view schematically showing an alternative embodiment of the elementary conductive pattern of FIG. **6**. Pattern **71** of FIG. **7** differs from the pattern of FIG. **6** by the shape of the branches originating from segments **12**. Pattern **71** comprises two branches **72** (respectively **72***a***1** and **72***a***2**, **72***b***1** and **72***b***2**, and **72***c***1** and **72***c***2**) extending from an intermediate point of each segment **12** along the same general direction as branches **32** of the pattern of FIG. **6**. However, unlike branches **32** of the pattern of FIG. **6**, branches **72** comprise a crenel-shaped extension of height H_c, extending along a direction approximately orthogonal to the general branch direction, towards the outside of the pattern.

Like pattern **61** of FIG. **6**, pattern **71** provides surfaces with three resonance frequencies. The provision of a crenel-shaped extension on branches **72** enables to vary the length of the branches more, which increases resonance frequency setting possibilities. Further, in the same way as for patterns **51** and **61** of FIGS. **5** and **6**, the resonance frequencies of the surfaces obtained from pattern **71** are insensitive to the orientation and to the polarization of electromagnetic waves.

As an example, by repeating pattern **71** according to a periodic layout of the type described in relation with FIG. **4**, the inventors have obtained a surface capable of shielding frequencies on the order of 0.9 and 1.8 GHz, by using the following parameters:

Parameter	L_s	D_b	D_m	L_b	W	L_{as}	L_{ab}	H_c
Value (mm)	25	9.1	0.75	7.5	0.5	4	5.75	5.9

The inventors have further obtained a surface capable of shielding frequencies on the order of 2.4 and 5.4 GHz by using the following parameters:

Parameter	L_s	D_b	D_m	L_b	W	L_{as}	L_{ab}	H_c
Value (mm)	9.6	3.6	0.5	2.9	0.25	2	1.6	1.8

The two above examples do not consider the third resonance frequency, which however exists.

FIG. **8** is a top view schematically showing an alternative embodiment of the elementary conductive pattern of FIG. **7**. In pattern **81** of FIG. **8**, each branch originating from a segment of the basic tripole comprises three crenel-shaped extensions of height H_c, extending along directions approximately orthogonal to the general branch direction, towards the outside of the pattern.

As an example, by repeating pattern **81** according to a periodic layout of the type described in relation with FIG. **4**, the inventors have obtained a surface capable of shielding frequencies on the order of 0.9, 1.8 GHz, and 2.1 GHz by using the following parameters:

Parameter	L_s	D_b	D_m	L_b	W	L_{as}	L_{ab}	H_c
Value (mm)	28.8	9.8	0.5	8.8	0.5	6.3	0.05	5

FIG. **9** is a top view schematically showing an alternative embodiment of the elementary conductive pattern of FIG. **8**. In pattern **91** of FIG. **9**, each branch originating from a segment of the basic tripole comprises crenel-shaped extensions of different heights, extending along directions approximately orthogonal to the general branch direction, alternately towards the outside and towards the inside of the pattern. Further, in pattern **91**, the fins associated with the branches are arranged in an arrow, as in pattern **51** of FIG. **5**.

FIG. **10** is a diagram illustrating the variation, according to frequency, of the transmission factor (in decibels) of a surface formed by the repeating of an elementary pattern **51** of FIG. **5**, for electromagnetic waves having different angles of incidence. Curves **101**, **102**, and **103** show the frequency responses of the surface for electromagnetic waves oriented along directions respectively forming angles of 0, 30, and 60° with the direction orthogonal to the surface plane. The selection of the parameters is such that the surface has three different resonance frequencies, respectively on the order of 0.9, 1.8, and 2.1 GHz. The diagram of FIG. **10** shows that the resonance frequencies of the surface, corresponding to negative peaks in curves **101**, **102**, **103**, are independent from the angle of incidence of waves. It should further be noted that the resonance frequencies are also independent from the wave polarization.

According to a preferred embodiment, the frequency-selective surfaces described hereabove are formed on paper- or cardboard-type supports, for example, on wall paper, on paper or cardboard lining plasterboards lined with cardboard, or on any other support capable of lining the walls of a room of a building. The conductive patterns are for example formed by printing with conductive inks.

According to an advantage of the above-described frequency-selective surfaces, the coverage rate of the conductive patterns is relatively low, for example, smaller than 15%. This enables to maintain a relatively low manufacturing cost for such surfaces.

Specific embodiments of the present invention have been described. Various alterations, modifications, and improvements will readily occur to those skilled in the art.

In particular, the elementary conductive patterns described in relation with FIGS. **7** to **9** may give rise to several variations. However, for each of these patterns, it may be chosen to arrange the fins associated with the branches of the pattern either in an arrow, as described in relation with FIG. **5**, or aligned along a same direction, as described in relation with FIG. **6**. Further, it will be within the abilities of those skilled in the art to implement the desired operation by varying the number, the direction, and the orientation of the crenel-shaped extensions formed of the pattern branches.

Further, in the elementary patterns described in relation with FIGS. **3** to **9**, a second generation of symmetrical branches originating from the main branches (**32**, **72**) may be provided to increase resonance frequency setting possibilities.

The invention claimed is:

1. A surface capable of filtering a plurality of frequency bands, this surface comprising a set of separate identical elementary conductive patterns, repeated according to a periodic layout on a dielectric support, the elementary pattern comprising:

a tripole formed of three identical segments extending in a star from a center; and

two branches extending symmetrically from an intermediate point of each segment, this intermediate point being located at a same distance from the center for each of the segments, the general directions of the two branches forming an angle of approximately 120° and defining an outward-pointing arrowhead, the branches associated with two different segments being non-secant,

the elementary pattern being repeated by translation along each of the directions of the segments so that a same distance separates each end of a segment of a pattern from the center of a neighboring pattern.

2. The surface of claim **1**, wherein the segments of the tripole form, two-by-two, angles of approximately 120°.

3. The surface of claim **1**, wherein the elementary pattern further comprises two first identical fins extending symmetrically from the end of each segment, the first fins forming an angle of approximately 120° and defining an arrowhead directed towards the outside of the pattern.

4. The surface of claim **1**, wherein the elementary pattern further comprises two first identical fins extending from the free end of each branch, each second fin forming an angle of approximately 60° with the general direction of the branch.

5. The surface of claim **4**, wherein the second fins of each branch form together an angle of approximately 120° and define an arrowhead directed towards the outside of the pattern.

6. The surface of claim **4**, wherein the second fins of each branch are aligned along a same direction, this direction intersecting the direction of the segment from which the branch originates.

7. The surface of claim **1**, wherein the branches comprise at least one crenel-shaped extension along a direction intersecting the general direction of the branch.

8. The surface of claim **1**, capable of filtering three frequency bands respectively centered on 0.9, 1.8, and 2.1 GHz.

9. The surface of claim **1**, capable of filtering two frequency bands respectively centered on 2.4 and 5.4 GHz.

10. The surface of claim **1**, wherein the dielectric support is a paper- or cardboard-type support and the conductive patterns are formed by printing with a conductive ink.

11. A use of the surface of claim **1** to filter three frequency bands located within the range from 0.9 to 5.4 GHz, wherein the overall dimensions of an elementary pattern approximately range from 1 to 10 centimeters, the lengths of each of these segments, branches, and fins being adjusted to select the three targeted frequency bands.

* * * * *